Parallel Computation for Whole Core Thermo-fluid Simulation of Prismatic Gas-Cooled Reactor

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1. Introduction

For a whole-core thermo-fluid analysis of a prismatic gas-cooled reactor, the development of a new computer code, named CORONA, is in progress at Korea Atomic Energy Research Institute (KAERI). One of the great challenges for a whole core thermo-fluid simulation of a prismatic gas-cooled reactor is the large computational expense required when an accurate result is targeted. In order to reduce the computational expense while achieving a reasonable accuracy, the CORONA code adopts a practical method proposed by the present authors [1]. However, even if the newly developed method is adopted, the computational cost might be still a great burden for a designer who wants a large number of calculations since a whole core thermo-fluid analysis requires a huge amount of computational meshes. In this work, therefore, a block-based parallel computation approach has been proposed, and realized in the CORONA code using a MPI (message passing index) protocol [2].

2. Computational Domain for Prismatic Core

Fig. 1 illustrates the reactor core arrangement of a prismatic gas-cooled reactor. The reactor core consists of hexagonal graphite fuel and reflector columns. Several fuel and reflector blocks (e.g., 6 blocks for the active core of PMR200) are stacked to form a column.

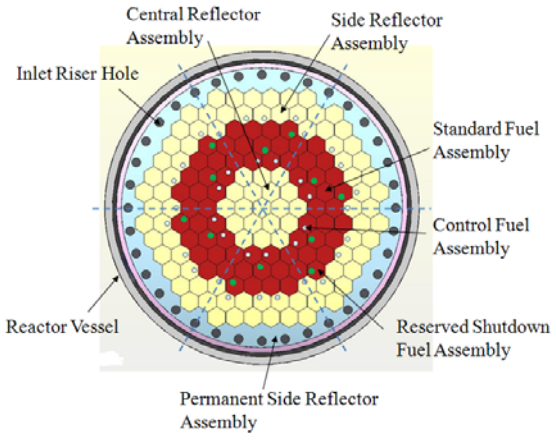

Fig. 1. Cross-sectional top view of PMR200 core [3].

Most of the helium coolant entering the core flows through the fuel coolant channels within the fuel blocks. A small fraction of the coolant bypasses the fuel block and passes through the gaps between the columns. It is called “bypass flow”. In addition, small lateral pressure differences that develop between the bypass gap flow and the coolant channel flow provide the potential for fluid mixing between the bypass gaps and the coolant channels. This flow is termed “cross flow”. Due to the bypass and cross flows, each fuel or reflector block is considered surrounded by the fluid boundaries as shown in Fig. 2.

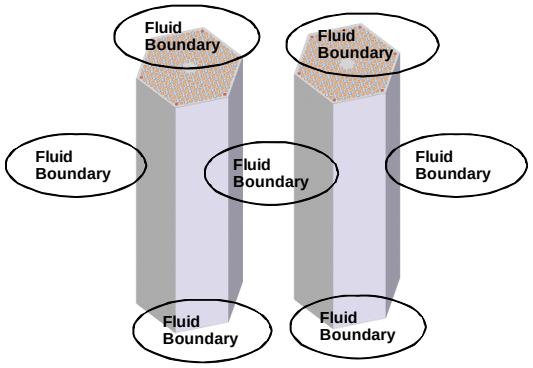

Fig. 2. Fuel blocks surrounded by fluid boundaries.

3. Block-Based Parallel Computation

The CORONA code solves the heat conduction in the fuel and reflector blocks.

$$\frac{\partial}{\partial t}(\rho_s C_s T_s) + \Delta \bullet (-k_s \nabla T_s) = q'''_{gen} \qquad (1)$$

The integration of Eq. (1) over a control volume yields the following discretised equation:

$$a_P^0 (T_{s,P} - T_{s,P}^0) + \sum_i [a_i (T_{s,P} - T_{s,i}) - s_i^{non}] = q'''_{gen} \delta V_P \qquad (2)$$

The discretized form of Eq. (1) at the fluid boundary is:

$$a_i (T_{s,P} - T_{s,i}) - s_i^{non} = Q_{conv,i} \qquad (3)$$

Eqs. (2) and (3) can be rearranged to the matrix form as

$$a_P^* T_{s,P} = \sum_i a_i^* T_{s,i} + b_P \qquad (4)$$

Eq. (4) can be solved simultaneously for all nodes if the material properties and $Q_{conv,i}$ are evaluated at the old iteration step.

The matrix shown in Eq. (4) can be simply decomposed into much smaller matrixes which

represent single (fuel or reflector) block. The decomposed matrix can be solved independently by using a parallel computation library.

4. Parallel Application to PMR200

In order to investigate the improved performance, the parallel calculations were performed for the 1/6 core of PMR200. The same problem was solved in [1] with a serial computation. Fig. 3 shows the calculation model. In order to magnify the difference in the computing speed, fine meshes with very tight convergence criteria were applied. The total numbers of solid and fluid nodes are ~35,000,000 and ~70,000, respectively.

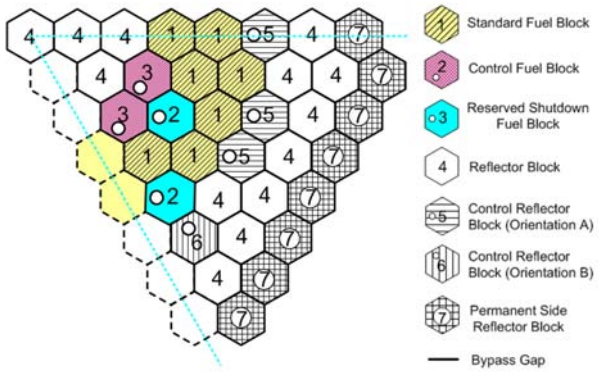

Fig. 3. 1/6 core calculation model for PMR200.

The calculations were carried out on the PC clusters with Microsoft Windows XP Professional x64 Edition. Table I shows the specification of the PC clusters used in this study. The communications between the PCs were made using Gigabit Ethernet Ports and 100 Mbps Ethernet cable via KAERI's internal computer network environment.

Table I: Specification of PC Clusters Used in This Work

	CPU	No. of CPUs	RAM
PC 1	Intel Xeon X5560 Quad Core, 2.8 GHz	2	64 GB
PC 2	Intel Xeon X5560 Quad Core, 2.8 GHz	2	64 GB
PC 3	Intel Xeon X5560 Quad Core, 2.8 GHz	2	64 GB
PC 4	Intel Xeon X5690 Six Core, 3.47 GHz	2	96 GB

Eight cases were tested to investigate the parallel performance and Table II summarizes the results for the tested problem. The maximum number of processors per PC was limited to 3 or 4 due to the RAM memory capacity. It was thoroughly checked that all the cases produced the same results. Table II shows that the computing speed is not always increased with the number of processors used. This seems mainly due to the limitation of the cache memory capacity. For the tested problem, the larger number of PCs results in the better performance. It was founded that most of the computing times are used for solving heat conduction matrixes and the required times for communications are very small.

Table II: Summary of Parallel Performance

Case	Machine Profile	Total No. of Processors	Computing Time (min.)	Relative Speed
1	PC1 x 1	1	3147.9	1.0
2	PC2 x 2	2	1723.0	1.8
3	PC3 x 3	3	2335.1	1.3
4	PC1 x 2 PC2 x 2 PC3 x 2	6	776.2	4.1
5	PC2 x 3 PC3 x 3	6	1199.9	2.6
6	PC1 x 2 PC2 x 2 PC3 x 2 PC4 x 2	8	617.9	5.1
7	PC1 x 3 PC2 x 3 PC3 x 3	9	887.0	3.5
8	PC1 x 3 PC2 x 3 PC3 x 3 PC4 x 4	13	528.2	6.0

5. Conclusions

In order to reduce the computational expense of a whole core thermo-fluid simulation for a prismatic gas-cooled reactor, a block-based parallelism was proposed and implemented in the CORONA code using a MPI protocol. The parallel computations were performed for the 1/6 core of PMR200. The results showed that significantly improved computing speeds can be achieved by using the block-based parallel computation.

Acknowledgements

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REFERENCES

[1] N. I. Tak, M. H. Kim, H. S. Lim, and J. M. Noh, "A Practical Method for Whole Core Thermal Analysis of Prismatic Gas-Cooled Reactor," Accepted for publication in Nuclear Technology, Jun. 21, 2011.
[2] Intel Corporation, Intel@ MPI Library for Windows OS, Documentation Number 316404-008.
[3] C. K. Jo, H. S. Lim, J. M. Noh, "Preconceptual Designs of the 200MWth Prism and Pebble-bed Type VHTR Cores," PHYSOR 2008, Interlaken, Switzerland, Sep. 14-19, 2008.